

The unusual photometric variability of the PMS star GM Cep

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Abstract

Results from *UBVRI* photometric observations of the pre-main sequence star GM Cep obtained in the period April 2011 - August 2014 are reported in the paper. Presented data are a continuation of our photometric monitoring of the star started in 2008. GM Cep is located in the field of the young open cluster Trumpler 37 and over the past years it has been an object of intense photometric and spectral studies. The star shows a strong photometric variability interpreted as a possible outburst from EXor type in previous studies. Our photometric data for a period of over six years show a large amplitude variability ($\Delta V \sim 2.3$ mag) and several deep minimums in brightness are observed. The analysis of the collected multicolor photometric data shows the typical of UX Ori variables a color reversal during the minimums in brightness. The observed decreases in brightness have a different shape, and evidences of periodicity are not detected. At the same time, high amplitude rapid variations in brightness typical for the classical T Tauri stars also present on the light curve of GM Cep. The spectrum of GM Cep shows the typical of classical T Tauri stars wide H α emission line and absorption lines of some metals. We calculate the outer radius of the H α emitting region as $10.4 \pm 0.5 R_{\odot}$ and the accretion rate as $1.8 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$.

Keywords: Pre-main sequence stars, T Tauri stars, GM Cep

1 Introduction

Photometric variability is a fundamental characteristic of the pre-main sequence (PMS) stars, which manifests as transient increases in brightness (outbursts), temporary drops in brightness (eclipses), irregular or regular variations for a short or long time scales. Both types of PMS stars the widespread low-mass ($M \leq 2M_{\odot}$) T Tauri Stars (TTSSs) and the more massive Herbig Ae/Be (HAEBE) stars indicate photometric variability with various amplitudes and periods (Herbst et al. 1994; Herbst et al. 2007). The TTSSs can be separated into two subclasses: Classical T Tauri (CTT) stars surrounded by a massive accretion disk and Weak line T Tauri (WTT) stars without indications of disk accretion (Bertout 1989). According to Herbst et al. (2007) the large amplitude variability of CTT stars is caused by magnetically channeled accretion from the circumstellar disk onto the stellar surface.

Some PMS stars show variability in brightness with very large amplitudes, dominated by fading or bursting behavior. The large amplitude outbursts can be grouped into two main types, named after their respective

prototypes: FU Orionis (FUor) and EX Lupi (EXor) (Reipurth & Aspin 2010). Both types of eruptive stars seems to be related to young stellar objects with massive circumstellar disks, and their outbursts are commonly attributed to a sizable increase in the disc accretion rate onto the stellar surface (Hartmann & Kenyon 1996). During the quiescence state FUors and EXors are normally accreting TTSSs, but due to thermal or gravitational instability in the circumstellar disk accretion rate enhanced by a few orders of magnitude up to $\sim 10^{-4} M_{\odot}/\text{yr}$.

A significant part of HAEBE stars and early type CTT stars show strong photometric variability with sudden quasi-Algol drops in brightness and amplitudes up to 2.5 mag. (*V*) (Natta et al. 1997; van den Ancker et al. 1998). During the deep minimums of brightness, an increase in polarization and specific color variability (called “blueing effect”) are observed. The prototype of this group of PMS objects with intermediate mass named UXors is UX Orionis. The widely accepted explanation of its variability is a variable extinction from dust clumps or fil-

aments passing through the line of sight to the star (Dullemond et al. 2003; Grinin et al. 1991). Normally the star becomes redder when its light is covered by dust, but when the obscuration rises sufficiently, the part of the scattered light in the total observed light become considerable and the star color gets bluer.

The PMS star GM Cep lie in the field of the young open cluster Trumpler 37 (~ 4 Myr old) at a distance of 870 pc (Contreras et al. 2002) and most likely is a member of the cluster (Marschall & van Altena 1987; Sicilia-Aguilar et al. 2005). The early long-term photographic observations of the star performed by Suyarkova (1975) and Kun (1986) indicate for a large amplitude photometric variability (the observed amplitudes are $\Delta m_{pg}=2.2$ mag and $\Delta V=2.15$ mag respectively). A multicolor photometric study based on optical, infrared and millimeter observations of GM Cep was reported by Sicilia-Aguilar et al. (2008). The authors found the star much brighter in 2006 than in 1990 and conclude that the most probable explanation for the brightness increase is an EXor type outburst.

According to Sicilia-Aguilar et al. (2008) GM Cep is a PMS star with solar mass ($M \sim 2.1M_{\odot}$) from G7V-K0V spectral type and with radius between 3 and 6 R_{\odot} . The observed strong IR excesses has been explained by the presence of a very luminous and massive circumstellar disk. The H α emission line in the spectrum of GM Cep has a strong P Cyg profile and the equivalent width of the line vary significantly from 6 \AA to 19 \AA (Sicilia-Aguilar et al. 2008). A variable accretion rate (up to $\sim 10^{-6} M_{\odot}/\text{year}$) are also detected in the study of Sicilia-Aguilar et al. (2008).

A long-term photometric study of GM Cep for several decades period was performed by Xiao et al. (2010). The photographic plate archives from Harvard College Observatory and from Sonneberg Observatory are used to construct the long-term B and V light curves of the star. The results suggest that GM Cep do not show fast rises in brightness typical of EXor variables and the light curves seem to be dominated by dips superposed on the quiescence state. Evidences for periodicity of observed dips in brightness were not found in the study of Xiao et al. (2010).

In our first paper (Semkov & Peneva 2012) the results from $BVRI$ optical photometric observations of the star collected in the period June 2008 - February 2011 are reported. During out photometric monitoring two deep minimums in brightness are observed. The collected multicolor photometric data shows the typical of UXor variables a color reversal during the minimums in brightness. Chen et al. (2012) reported results from intensive BVR photometric monitoring of GM Cep during the period 2009-2011. They confirm the UXor nature of variability and suggest an early stage of planetesimal formation in the star environment. Chen & Hu

(2014) suggest a periodicity of about 300 days at the observed deep declines in brightness.

Recent $BVRI$ CCD photometric observations of GM Cep collected in the period April 2011 - August 2014 are reported in the present paper. The multicolor observations give us the opportunity to clarify the mechanism of the brightness variations.

2 Observations

Our photometric CCD data were obtained in two observatories with four telescopes: the 2-m Ritchey-Chrétien-Coudé (2-m), the 50/70-cm Schmidt (Sch) and the 60-cm Cassegrain (60-cm) telescopes of the National Astronomical Observatory Rozhen (Bulgaria) and the 1.3-m Ritchey-Crétien (1.3-m) telescope of the Skinakas Observatory¹ of the Institute of Astronomy, University of Crete (Greece). The technical parameters and chip specifications for the cameras used with the 2-m RCC, the 1.3-m RC and the 50/70-cm Schmidt telescopes are summarized in Semkov & Peneva (2012). Observations with the 60-cm Cassegrain telescope were performed with FLI PL09000 CCD camera (3056×3056 pixels, $12 \mu\text{m}$ pixel size, 16.8×16.8 arc. min. field, $8.5 e^-$ rms RON) As references, we used the comparison sequence of fifteen stars in the field around GM Cep published in Semkov & Peneva (2012).

All frames were taken through a standard Johnson-Cousins set of filters. Twilight flat fields in each filter were obtained each clear evening. All frames obtained with the ANDOR and Vers Array cameras are bias subtracted and flat fielded. CCD frames obtained with the FLI PL16803 and FLI PL09000 cameras are dark subtracted and flat fielded. Aperture photometry was performed using DAOPHOT routines. All the data were analyzed using the same aperture, which was chosen as 6 arc sec in radius, while the background annulus was from 10 to 15 arc sec.

A medium-resolution spectrum of GM Cep was obtained on 2008 June 27 with the 1.3-m RC telescope in Skinakas Observatory. The focal reducer, ISA 608 spectral CCD camera (2000×800 pixels, $15 \times 15 \mu\text{m}$ pixel size), 1300 lines/mm grating and $160 \mu\text{m}$ slit were used. The combination of used CCD camera, slit and grating yield a resolving power $\lambda/\Delta\lambda \sim 1300$ at H α line. The exposure of GM Cep were followed immediately by an exposure of an FeHeNeAr comparison lamp.

¹Skinakas Observatory is a collaborative project of the University of Crete, the Foundation for Research and Technology - Hellas, and the Max-Planck-Institut für Extraterrestrische Physik.

Table 1: Photometric *IRVB* observations of GM Cep during the period April 2011 - August 2014

J.D. (24...)	I	R	V	B	Tel	J.D. (24...)	I	R	V	B	Tel
55656.458	11.61	12.53	13.38	14.70	Sch	55896.222	12.62	13.79	14.70	16.00	Sch
55659.492	11.73	12.62	13.47	14.87	2-m	55925.200	12.74	13.90	14.87	16.14	Sch
55683.557	11.83	12.76	13.68	15.10	2-m	55928.207	12.41	13.57	14.54	15.94	Sch
55703.359	11.67	12.65	13.48	14.78	Sch	55957.187	12.06	13.01	13.95	-	2-m
55704.370	11.62	12.56	13.43	14.74	Sch	55958.211	12.01	12.95	13.88	15.33	2-m
55705.376	11.57	12.50	13.34	14.66	Sch	56003.528	12.19	13.31	14.29	15.72	Sch
55706.362	11.59	12.52	13.36	14.67	Sch	56015.536	12.22	13.26	14.28	15.74	2-m
55707.358	11.62	12.55	13.42	14.74	Sch	56030.460	12.12	13.19	14.13	15.50	Sch
55721.357	11.71	12.64	13.54	14.95	2-m	56060.390	12.19	13.34	14.31	15.68	Sch
55722.396	11.62	12.56	13.45	14.81	Sch	56068.375	12.11	13.20	14.18	15.63	Sch
55734.452	11.78	12.77	13.69	15.07	Sch	56091.418	12.01	13.06	14.00	15.35	Sch
55735.410	11.82	12.83	13.75	15.12	Sch	56092.406	11.97	13.00	13.93	15.30	Sch
55736.407	11.98	13.06	14.00	15.35	Sch	56094.469	12.21	13.21	14.18	15.60	2-m
55737.425	12.02	13.10	14.05	15.39	Sch	56096.423	11.96	12.99	13.94	15.31	Sch
55739.553	11.85	12.81	13.71	-	60-cm	56120.397	11.84	12.78	13.70	15.06	Sch
55770.389	11.84	12.86	13.78	15.14	Sch	56121.291	11.89	12.87	13.76	15.14	Sch
55785.307	-	12.47	-	-	Sch	56122.352	11.93	12.91	13.81	15.18	Sch
55786.268	-	12.47	13.26	14.54	Sch	56123.416	11.98	12.95	13.86	15.23	Sch
55787.286	-	12.37	13.19	14.45	Sch	56137.318	11.74	12.67	13.51	14.79	Sch
55788.314	-	12.40	13.22	14.47	Sch	56139.292	11.80	12.75	13.63	14.97	1.3-m
55789.321	-	12.44	13.28	14.55	Sch	56139.305	11.81	12.79	13.62	14.92	Sch
55790.250	11.52	12.38	13.21	14.53	1.3-m	56141.385	11.72	12.64	13.50	14.86	1.3-m
55790.261	-	12.41	13.22	14.46	Sch	56142.256	11.73	12.64	13.51	14.85	1.3-m
55791.277	11.48	12.34	13.17	14.47	1.3-m	56145.555	11.62	12.54	13.34	14.49	60-cm
55791.292	11.48	12.37	13.17	14.44	Sch	56157.592	11.76	12.68	13.54	14.88	1.3-m
55792.244	11.53	12.38	13.22	14.54	1.3-m	56159.371	11.67	12.56	13.42	14.76	Sch
55792.279	11.52	12.43	13.23	14.50	Sch	56160.352	11.58	12.46	13.29	14.60	Sch
55797.343	11.48	12.35	13.16	14.45	Sch	56161.374	11.59	12.50	13.31	14.63	Sch
55798.328	11.47	12.35	13.16	14.45	Sch	56162.357	11.65	12.55	13.38	14.69	Sch
55799.342	11.51	12.41	13.24	14.52	Sch	56166.267	11.66	12.56	13.40	14.70	Sch
55814.349	12.01	13.03	13.98	15.30	Sch	56167.300	11.59	12.50	13.31	14.60	Sch
55815.276	11.88	12.88	13.81	15.23	1.3-m	56168.310	11.54	12.42	13.26	14.55	Sch
55815.316	-	12.87	-	-	Sch	56169.287	11.58	12.45	13.30	14.62	Sch
55816.326	11.86	12.86	13.80	15.18	Sch	56173.360	11.48	12.32	13.11	14.40	1.3-m
55816.433	11.86	12.87	13.70	15.25	1.3-m	56174.338	11.41	12.24	13.03	14.30	1.3-m
55817.244	11.87	12.90	13.85	15.24	Sch	56178.311	11.43	12.25	13.04	14.32	1.3-m
55818.275	-	12.90	-	-	Sch	56179.485	11.55	12.41	13.22	14.53	1.3-m
55819.246	11.88	12.92	13.87	15.24	Sch	56180.346	11.55	12.41	13.24	14.54	1.3-m
55820.276	-	13.16	-	-	Sch	56181.273	11.44	12.27	13.07	14.33	60-cm
55821.246	11.98	13.07	14.04	15.35	Sch	56182.268	11.43	12.26	13.06	14.33	1.3-m
55822.238	11.88	12.93	13.90	15.30	Sch	56183.280	11.43	12.25	13.04	11.25	60-cm
55824.237	11.89	12.93	13.88	15.29	1.3-m	56183.393	11.44	12.27	13.07	14.33	1.3-m
55828.281	11.75	12.77	13.71	15.13	Sch	56192.311	11.46	12.29	13.11	14.36	60-cm
55842.306	11.68	12.65	13.55	14.95	1.3-m	56193.308	11.54	12.39	13.21	14.51	1.3-m
55848.297	11.76	12.79	13.69	15.09	1.3-m	56193.360	11.51	-	-	-	Sch
55864.275	12.14	13.11	14.10	15.59	2-m	56194.341	11.56	12.43	13.24	14.56	Sch
55865.268	11.99	12.96	13.92	15.38	2-m	56195.270	11.45	12.28	13.09	14.36	Sch
55866.218	12.03	12.96	13.93	15.38	2-m	56208.248	11.86	12.82	13.71	15.09	Sch
55890.202	12.33	13.51	14.50	15.68	60-cm	56209.251	11.98	12.97	13.87	15.26	Sch
55892.232	12.39	13.43	14.50	15.98	2-m	56210.242	11.98	12.95	13.86	15.22	Sch
55895.212	12.64	13.80	14.75	16.07	Sch	56212.281	11.74	12.66	13.57	14.92	60-cm

Table 1: continued.

J.D. (24...)	I	R	V	B	Tel	J.D. (24...)	I	R	V	B	Tel
56214.252	11.73	12.60	13.47	14.85	2-m	56513.419	11.76	12.71	13.58	14.94	60-cm
56226.374	11.62	12.51	13.38	14.73	Sch	56514.386	11.68	12.59	13.48	14.86	60-cm
56231.280	11.79	12.76	13.71	15.07	60-cm	56540.346	11.61	12.48	13.32	14.63	Sch
56249.272	11.64	12.56	13.42	14.77	Sch	56541.380	11.61	12.47	13.32	14.62	Sch
56250.226	11.65	12.58	13.45	14.79	Sch	56542.420	11.65	12.52	13.38	14.70	Sch
56275.302	11.71	12.59	13.45	14.82	2-m	56543.376	11.70	12.55	13.38	14.69	2-m
56276.259	11.64	12.51	13.35	14.67	2-m	56553.326	11.77	12.70	13.56	14.91	1.3-m
56292.368	11.58	12.47	13.34	14.70	60-cm	56577.469	11.57	12.45	13.30	14.65	60-cm
56294.303	11.51	12.41	13.31	14.60	60-cm	56578.482	11.60	12.46	13.31	14.68	60-cm
56295.349	11.56	12.45	13.30	14.62	60-cm	56604.444	11.65	12.63	13.55	-	60-cm
56296.327	11.61	12.49	13.37	14.72	60-cm	56636.280	11.93	12.96	14.00	15.51	2-m
56309.254	11.75	12.67	-	-	Sch	56655.226	12.32	13.54	14.55	15.94	Sch
56312.252	11.72	12.65	13.58	15.00	2-m	56656.234	12.34	13.56	14.57	15.91	Sch
56329.210	11.71	12.67	13.57	14.93	Sch	56657.212	12.39	13.59	14.60	15.97	Sch
56330.218	11.82	12.81	13.75	15.13	Sch	56681.239	12.25	13.43	14.44	15.87	Sch
56356.261	11.52	12.41	13.30	14.58	60-cm	56694.239	12.23	13.28	14.32	15.83	2-m
56369.561	11.52	12.34	13.16	14.42	2-m	56738.547	12.38	13.55	14.51	15.81	Sch
56392.487	11.50	12.35	13.17	14.46	Sch	56799.494	12.12	13.25	14.16	15.58	Sch
56394.432	11.48	12.35	13.17	14.42	Sch	56801.344	11.93	12.92	13.88	15.32	2-m
56415.444	12.22	13.20	14.10	15.44	Sch	56832.325	11.60	12.54	13.43	14.85	2-m
56417.414	11.82	12.69	13.59	14.99	2-m	56834.319	11.67	12.59	13.53	14.94	2-m
56443.440	12.00	12.94	13.84	15.19	Sch	56835.481	11.66	12.60	13.55	14.92	2-m
56444.410	11.95	12.90	13.78	15.14	Sch	56837.392	11.79	12.82	13.77	15.13	Sch
56478.411	11.68	12.58	13.44	14.83	2-m	56838.374	11.82	12.85	13.79	15.14	Sch
56506.411	11.72	12.58	13.40	14.73	2-m	56859.459	11.67	12.71	13.62	14.96	60-cm
56507.408	11.85	12.71	13.55	14.88	2-m	56860.469	11.69	12.71	13.60	14.95	60-cm
56508.446	11.90	12.77	13.60	14.93	2-m	56863.425	11.83	12.84	13.84	15.22	Sch
56509.344	12.01	12.93	13.78	15.08	Sch	56873.349	11.72	12.74	13.68	15.05	Sch
56510.411	12.27	13.25	14.14	15.43	60-cm	56874.377	11.75	12.75	13.68	15.08	Sch
56511.435	12.11	13.08	13.95	15.24	Sch	56888.403	11.65	12.61	13.49	14.80	Sch
56511.452	12.10	13.06	13.93	15.28	60-cm	56889.338	11.64	12.61	13.47	14.81	Sch
56512.441	11.90	12.85	13.70	15.03	60-cm	56899.325	11.64	12.63	13.50	14.84	1.3-m

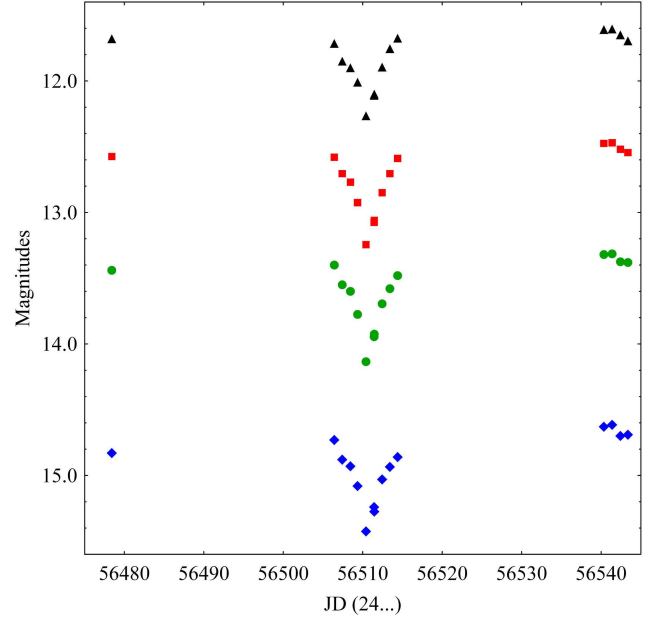
Table 2 Data from *U* band observations of GM Cep during the period July 2008 - February 2014

Date	J.D. (24...)	U	Tel	CCD
08 Jul 2008	54656.464	14.79	1.3-m	ANDOR
13 Jul 2008	54661.428	15.61	1.3-m	ANDOR
24 Jul 2008	54672.335	15.37	1.3-m	ANDOR
25 Jul 2008	54673.355	15.21	1.3-m	ANDOR
11 Jun 2009	54994.581	16.08	1.3-m	ANDOR
14 Jun 2009	54997.531	16.35	1.3-m	ANDOR
17 Jun 2009	55000.584	16.45	1.3-m	ANDOR
23 Jun 2009	55006.517	15.83	1.3-m	ANDOR
01 Jul 2009	55014.517	16.38	1.3-m	ANDOR
03 Jul 2009	55016.576	16.16	1.3-m	ANDOR
06 Jul 2009	55019.512	16.47	1.3-m	ANDOR
09 Jul 2009	55022.521	16.64	1.3-m	ANDOR
18 Jul 2009	55031.504	16.53	1.3-m	ANDOR
24 Jul 2009	55037.526	16.59	1.3-m	ANDOR
31 Jul 2009	55044.366	16.89	1.3-m	ANDOR
25 Nov 2009	55161.217	15.09	2-m	VA
13 Jul 2010	55391.338	16.38	2-m	VA
17 Jul 2010	55395.341	16.42	2-m	VA
11 Aug 2010	55420.051	16.20	1.3-m	ANDOR
12 Aug 2010	55421.367	16.13	1.3-m	ANDOR
25 Aug 2010	55434.316	16.09	1.3-m	ANDOR
26 Aug 2010	55435.352	16.09	1.3-m	ANDOR
29 Oct 2010	55499.295	15.68	2-m	VA
30 Oct 2010	55500.238	15.43	2-m	VA
01 Nov 2010	55502.259	15.50	2-m	VA
10 Sep 2011	55815.276	15.99	1.3-m	ANDOR
31 Oct 2011	55866.218	16.02	2-m	VA
03 Sep 2012	56174.338	14.89	1.3-m	ANDOR
09 Sep 2012	56180.346	15.13	1.3-m	ANDOR
11 Sep 2012	56182.268	14.92	1.3-m	ANDOR
22 Sep 2012	56193.308	15.06	1.3-m	ANDOR
03 Aug 2013	56508.446	15.55	2-m	VA
07 Sep 2013	56543.376	15.15	2-m	VA
05 Feb 2014	56694.239	16.93	2-m	VA

3 Results and Discussion

3.1 Photometric monitoring

The results of our photometric CCD observations of GM Cep are summarized in Table 1. The columns provide the Julian date (J.D.) of observation, *IRVB* magnitudes, and the telescope used. In the column Tel abbreviation 2-m denote the 2-m Ritchey-Chrétien-Coudé, Sch - the 50/70-cm Schmidt, 60-cm - the 60-cm Cassegrain and 1.3-m the 1.3-m Ritchey-Crétien telescope. The typical instrumental errors from *IRVB* photometry are reported in our previous study (Semkov & Peneva 2012). In addition, we present in Table 2 data from observations in *U* filter for the whole period of our photometric monitoring (2008 - 2014). The

**Figure 2.** *BVRI* light curves during the deep minimum on August 2013

values of instrumental errors of *U* band photometry are in the range 0.04-0.08 mag.

The *UBVRI* lights curves of GM Cep from all our observations (Semkov & Peneva (2012) and the present paper) are shown in Fig. 1. On the figure triangles denote *I*-band data; squares - *R*-band, circles - *V*-band; diamonds - *B*-band, and the pluses - *U*-band.

The new photometric data showed continued strong brightness variability of GM Cep as the registered in the previous studies (Sicilia-Aguilar et al. 2008; Xiao et al. 2010; Semkov & Peneva 2012; Chen et al. 2012). Out of deep minimums GM Cep shows significant brightness variations in the time scale of days and months. In our first paper (Semkov & Peneva 2012) we presented data about two observed deep minimums in brightness. During the period April 2011 - August 2014 three new well defined minimums in brightness are observed. The third registered minimum is very extended covering the period from the end of 2011 to mid-2012. The fourth minimum has a duration of only 8-9 days and it is registered in August 2013. A drop in brightness with 0.74 mag. (*V*) for a period of four days and a rise to the maximum level for the same time was observed. The fifth minimum is registered in the period from December 2013 to June 2014 and it resembles in duration and amplitude the minimum of 2011/2012.

The summarized results of over six years period of observations show very strong photometric variability. We have registered five deep minimum in brightness in

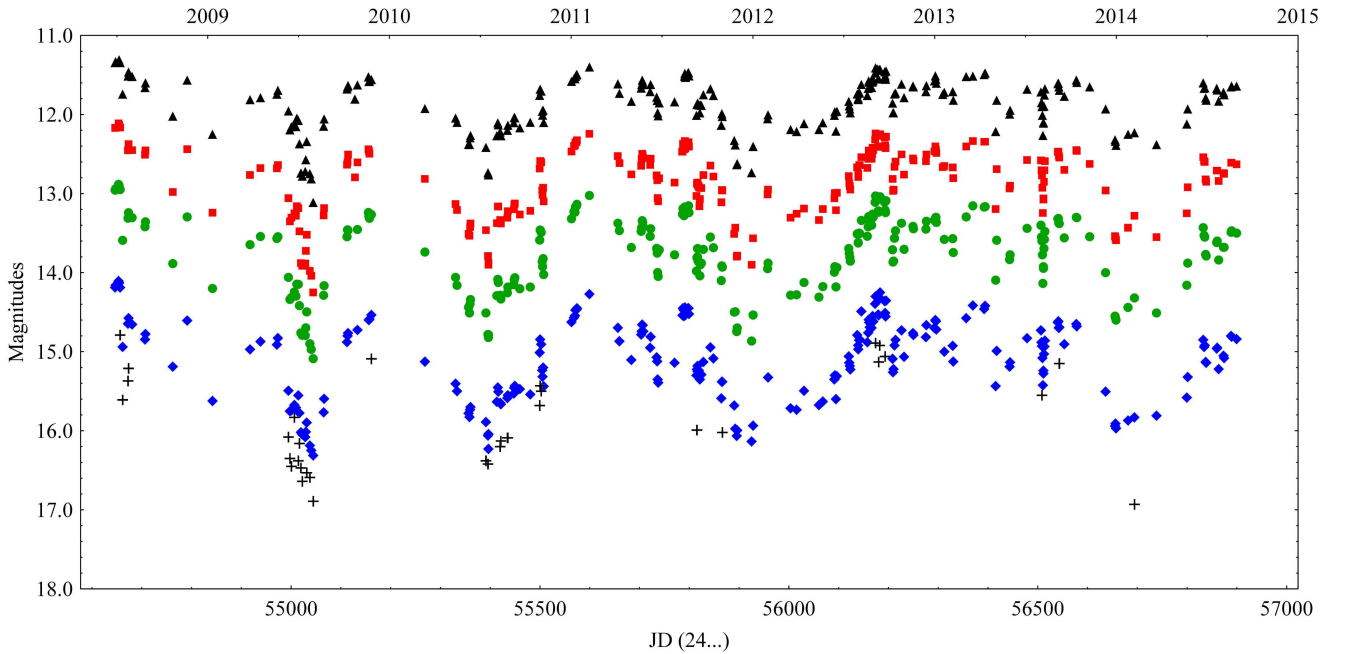


Figure 1. *UBVR* light curves of GM Cep for the whole period of our photometric monitoring (2008 - 2014)

the light curve of GM Cep. The first two minimums observed in 2009 and 2010 have a duration of between one and two months, the third (2011/2012) and the fifth (2013/2014) minimum have duration at about half an year, and the fourth minimum (August 2013) has at one week duration (Fig. 2). Other drops in brightness with duration of about a week have not been surely registered in our photometric study, but the occurrence of such short events cannot be ruled out. Our photometric data do not confirm the existence of a long-term periodicity, as suggested by Chen & Hu (2014). Eclipses in the light curve of the star are probably caused by objects of different sizes and densities. Such objects could be massive dust clumps orbiting the star, inhomogeneous structures of the circumstellar disk or planetesimals at different stages of formation.

Another important result of our study is the change in color of GM Cep at the deep minimums. Using data from our *UBVR* photometry the four color-magnitude diagrams ($U - B/B$, $B - V/V$, $V - R/V$ and $V - I/V$) of the star are constructed and displayed on Fig. 3. The existence of a turning point of each of the diagrams is seen on the figure. In accordance with the model of dust-clump obscuration, the observed color reversal is caused by the scattered light from small dust grains. Generally the star becomes redder when its light is covered by dust clumps on the line of sight. But when the obscuration rises enough, the part of the scattered light in the total observed light becomes significant and the star color gets bluer. For each color,

such a turning point occurs at different stellar brightness, for example on $V/B - V$ diagram the turning point occurs at $V \sim 14.0$ mag., while on $V/V - I$ diagram at $V \sim 14.6$ mag. As we mentioned in our first paper (Semkov & Peneva 2012) “the observed change of color indices suggest for existence of a color reversal in the minimum light, a typical feature of the PMS stars from UXor type”. The new data confirm the presence of “blueing effect” at minimum light and they are independent evidence that the variability of GM Cep is dominated by variable extinction from the circumstellar environment.

After analysis of data collected our conclusion is that the photometric properties of GM Cep can be explained by superposition of both: (1) highly variable accretion from the circumstellar disk onto the stellar surface, and (2) occultation from circumstellar clumps of dust, planetesimals or from features of the circumstellar disk. Our photometric results for the period June 2008 - August 2014 suggest that the variable extinction dominates the variability of GM Cep. In low accretion rates both types of variability can act independently during different time periods and the result is the complicated light curve of GM Cep.

Due to the complex circumstellar environment around PMS stars, such a mixture of different types of photometric variability can be expected. In recent studies, a similar superposition of the both types of variability is seen on the long-term light curve of others PMS stars: V1184 Tau

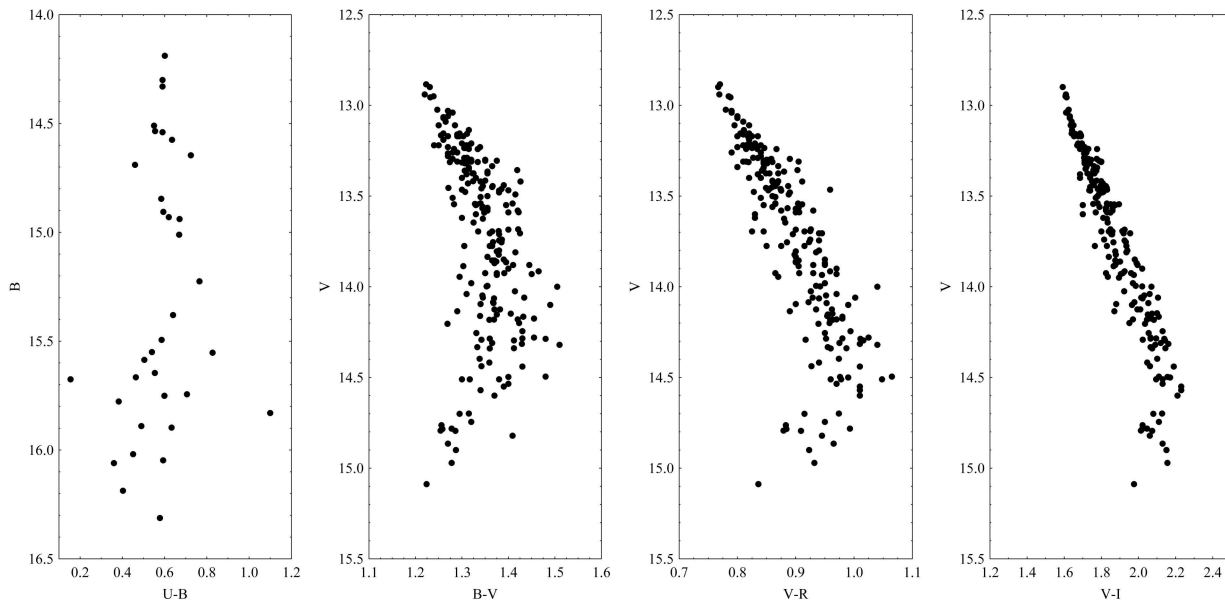


Figure 3. The color-magnitude diagrams of GM Cep in the period of observations June 2008 - June 2014

(Semkov et al. 2008; Barsunova et al. 2006), V1647 Ori (Aspin et al. 2009), V582 Aur (Semkov et al. 2013) and V2492 Cyg (Hillenbrand et al. 2013). Recently, the results of two long-term photometric studies in the field of NGC 7000/IC 5070 (Findeisen et al. 2013; Poljančič Beljan et al. 2014) has shown that the eclipsing phenomena are widespread type of variability in among the PMS stars. It seems that the time variable extinction is characteristic not only of HAEBE and early type CTT stars but is also a common phenomenon during the evolution of all types of PMS stars.

3.2 Spectral data

The medium-resolution spectrum of GM Cep obtained in Skinakas Observatory is shown in Fig. 4. At the time of spectral observations (June 2008) the star was at the maximal level of brightness ($V \sim 12.9$ mag). The analysis of spectrum was made using the standard procedures in IRAF. We fits the line profiles with Gaussian and estimate the equivalent width of the lines. The spectrum shows the typical of CTT stars absorption lines of iron, calcium, sodium and other metals and a very broad $H\alpha$ emission line.

The double-line profile of the $H\alpha$ line suggest that the line is formed in a disk-like region (Horne & Marsh 1986). There are similarities between the profiles of the $H\alpha$ lines of GM Cep and some Be/X-ray binary stars, e. g. LS I +61 303 (Zamanov et al. 2010). The circumstellar disks in Be/X-ray binaries are formed from the fast rotation of the Be star, non-radial pulsations and slow and dense

Table 3 The parameters of the two peaks and the central dip of the $H\alpha$ line. Given are as follows: equivalent width (EW) of the line, full width at half maximum (FWHM) and the radial velocity (V_{rad}).

	EW [Å]	FWHM [Å]	V_{rad} [km s ⁻¹]
Blue peak	-1.09 ± 0.02	3.00 ± 0.02	-392.3 ± 0.1
Central dip	$+0.23 \pm 0.02$	1.06 ± 0.02	-231.5 ± 0.1
Red peak	-5.39 ± 0.02	5.05 ± 0.02	5.9 ± 0.1

equatorial wind. The PMS stars are characterized with strong stellar winds. In case of GM Cep, the wind probably form disk-like structure near the surface of the star. The depth of the central absorption of $H\alpha$ line suggest that the inclination of the star to the line of sight is $i \sim 75^\circ$ (Hanuschik 1996). In Table 3 are given the measured parameters of the $H\alpha$ line.

For rotationally dominated profiles, the peak separation can be regarded as a measure of the outer radius of the $H\alpha$ emitting disk (Huang 1972):

$$R_{disk} = \frac{GM_* \sin^2 i}{(0.5 \Delta V)^2}, \quad (1)$$

From the spectrum we estimate $\Delta V = 379.4 \pm 0.3$ km s⁻¹ (the distance between the blue and red peaks of $H\alpha$). This velocity is connected with the outer edge of the disk. Using mass of the star $M_* = 2.1 M_\odot$ and inclination angel $i = 75^\circ$, we calculate the outer radius of the $H\alpha$ emitting region to be $10.4 \pm 0.5 R_\odot$.

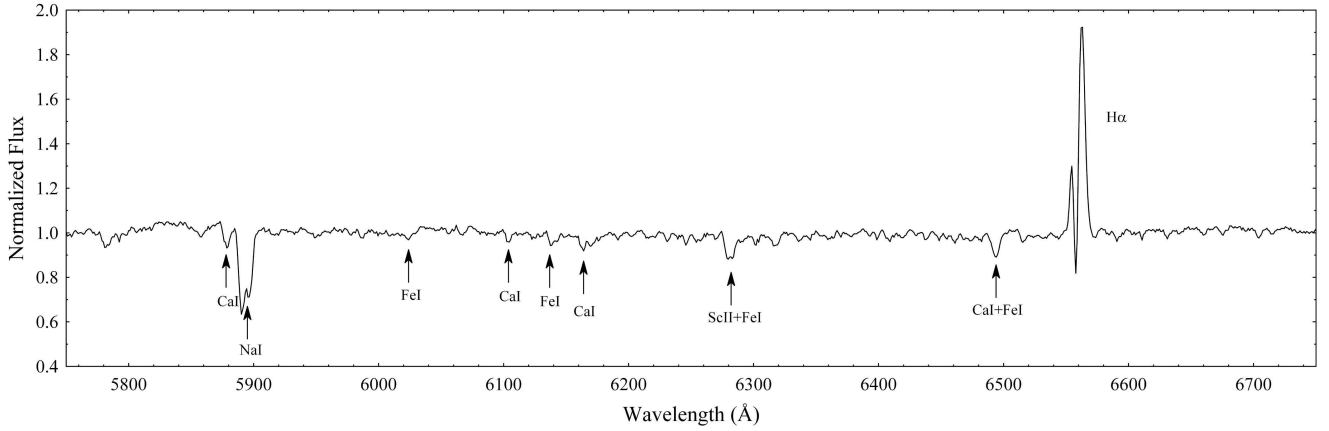


Figure 4. Spectrum of GM Cep obtained on 2008 June 27 with the 1.3-m RC telescope in Skinakas Observatory

Using the correlation between the $H\alpha$ velocity wings at 10% of the maximum ($V_{H\alpha 10\%}$) and \dot{M}_{ac} , we can estimate the accretion rate (Natta et al. 2004):

$$\log \dot{M}_{ac} = -12.89(\pm 0.3) + 9.7(\pm 0.7) \times 10^{-3} V_{H\alpha 10\%} \quad (2)$$

where $V_{H\alpha 10\%}$ is in km s^{-1} and \dot{M}_{ac} is in $M_{\odot} \text{ yr}^{-1}$.

For measured velocity 633 km s^{-1} on 10% of the maximum, the accretion rate is $1.8 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$, which is close to the value $3 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$, obtained by Sicilia-Aguilar et al. (2008).

4 Conclusion

Photometric and spectral data presented in this paper show the usefulness of systematically monitoring of PMS stars with large amplitude variability. On the basis of our photometric monitoring over the past six years, we have confirmed that the variability of GM Cep is dominated by fading events rather than by bursting events. The effect of color reversal at the minimum light is evidence of variable extinction from the circumstellar environment. We plan to continue our photometric monitoring of the star during the next years and strongly encourage similar follow-up observations.

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